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VEHICLE OVERTURNING VULNERABILITY FROM AIR BLAST LOADS

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Introduction

The overturning response of a vehicle to air blast loads derived from a nuclear blast environment is presented herein. The vehicle considered is representative of an armored personnel carrier (APC). The orientation of the vehicle is side-on to the air blast shock front. It is assumed that either there is sufficient friction at the vehicle/ground surface interface or that the downwind wheels are chocked so that there is no translation at the downwind wheels, i.e., the roll over point. In addition, the vehicle is assumed to behave as a rigid body. That is, the suspension systems is taken as rigid, so that the wheels and axles rotate in unison with the body. It can be shown that this assumption slightly overestimates the overturning resistance of vehicles with suspension systems. For a stiff suspension system, such as that of the APC, the rigid body behavior assumption is justified.

The air blast loads are obtained by considering the diffraction and drag forces, acting on a series of interconnected rectangular blocks positioned in space which represent the aerodynamic model of the vehicle. The separate block loads at any time step are summed-up to obtain the total load history acting on the rigid body, single degree of freedom dynamic model. The only motion possible for this analysis is rotation about the rollover point. The effect of overturning restraint systems has been included in the analysis by incorporating a perfectly plastic vehicle to ground connection on the upwind side of the vehicle. The results presented give the threshold nuclear environment that just causes overturning. The threshold environment is given in terms of a peak overpressure corresponding to a weapon yield. Results are presented for a range of weapon yields from 1KT to 1MT.

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Method of Analysis

A computer program (OVRTRN) was used to numerically determine the overturning potential of an airblast load applied to a vehicle. The program incorporates the recently developed Ballistic Research Laboratory BLOP program to obtain the airblast loading on the vehicle.

The OVRTRN code can be used to evaluate both the reflected pressure loading and the drag loading that occurs from the dynamic pressure. The reflected pressure loading can be optionally included as an impulse load which imparts an initial velocity to the vehicle. It is also possible to evaluate the influence of nonlevel terrain since an initial angle (from the horizontal) of the ground surface can be specified by the user. In addition, the effect of a moving vehicle can be approximated by the application of a lateral load to the center of mass to simulate the centrifugal loading of the vehicle traveling around a curve. This feature can also be used to study the effect of perfectly plastic restraints connected between the vehicle and the ground. The overturning resistance provided by the restraint or tie downs can be easily related to a centrifugal force applied to the center of mass toward ground zero.

The numerical integration solution procedure of the equations of motion employed in the OVRTRN program is an explicit, central difference technique. The solution is automatically terminated if the vehicle rotation exceeds the instability rotation angle. Instability is assumed to occur when the center of mass rotates to a point directly over the rollover point. It is noted that for the case where restraints are included or there is a centrifugal force toward ground zero that larger rotations can occur before tipover. For this case, it is necessary to continue the solution further to establish whether tipover occurs.

The technique used to analyze the vehicle for overturning was to assume that the complete system is a single rigid body incapable of sliding motion. This assumes that the coefficient of friction between the wheels and the ground surface is sufficiently high and that any lifting forces acting on the vehicle are negligible compared to its weight. This latter assumption assures that there will be a nontensile vertical interface force (reaction) between the vehicle and the ground surface.

Figure 1 illustrates an APC subjected to side-on blast loading and the only degree-of-freedom possible, which is the rotation (θ) about the downwind track/ground surface interface, Point A. The time dependent blast load resultant lateral force is denoted by F(t). The height or point of application of the blast load, h(t), is also time dependent since some of the smaller components parts (e.g., wheels) which are modeled as rectangular boxes in the BLOP code will have shorter duration diffraction phase loading than other components. However, after the diffraction phase loading is over, the point of application of the resultant blast load will not appreciably change. The angle, θ, represents the rotation of the rigid body vehicle model from its initial position θ_o. If the vehicle is on level ground, then θ_o = 0.0. It is also assumed that the rigid body is initially at rest ($\dot{\theta}_o = 0$); however, there is an option to provide for both nonzero initial values of θ_o and $\dot{\theta}_o$. An initial nonzero θ_o would represent a rigid body on nonlevel ground and nonzero $\dot{\theta}_o$ can be used to represent the short duration reflected pressure and/or diffraction phase loading impulse. An initial value of $\theta_o > o$ indicates that the ground slopes away from ground zero and this would increase the vulnerability of the vehicle to overturning.

The effect of centrifugal loading to simulate vehicle travel at constant velocity around a curve or the equivalent overturning resistance offered by a perfectly plastic restraint is modelled by the application of a horizontal force resultant, γW, applied laterally to the center of mass as indicated in Figure 1.

The equation of motion that governs the time dependent rotation of the rigid body is

$$I_A \ddot{\theta} + M_R\{\theta\} = M_F\{t,\theta\} \qquad (1)$$

where I_A = second moment of mass of the rigid body about point A

$M_R\{\theta\}$ = restoring moment = $Wx\{\theta\} + \gamma Wy\{\theta\}$ (2)

$M_F\{t,\theta\}$ = $F\{t\} \cdot H\{t,\theta\}$ = air blast overturning moment (3)

$x\{\theta\}$ = rotational dependent horizontal distance from point A to the center of mass

$y\ \{\theta\}$ = rotational dependent vertical distance from point A to center of mass

W = total weight of rigid body

$F\ \{t\}$ = time dependent horizontal force acting on rigid body

$H\{t,\theta\}$ = time and rotation dependent vertical location of $F\{t\}$ from point A.

The parameter $H\{t,\theta\}$ can be used to compute the overturning moment, M_F, rather than merely the BLOP code computed $h\{t\}$ for the following reason. As the rigid body rotates, it is reasonable to assume that the BLOP code computed overturning moment (which is the lateral force times to height to its point of action) will be increased from at least two sources: (1) lift forces will be produced on the underside of the rigid body, and (2) the drag area will be increased (at least for the initial rotations). In order to approximately account for the rotational increase to the overturning moment, it can be assumed that the $h\{t\}$ variable should be modified to produce $H\{t,\theta\}$ which is used in Equation (3) to compute the overturning moment. The procedure used assumes that the location of the center-of-pressure (C.P.) is a function of the rotation (θ), viz,

$$H\{t,\theta\} = h\{t\}\cos\theta + \sin\theta \qquad (4)$$

The restoring moment is the first moment of the vehicle weight gravitational vector, W, and the horizontal force, γW, about point A. Initially, the location of the W and γW vectors for level ground is $x = x_o$ and $y = y_o$, respectively. The distance from point A to the center of mass is

$$R = x_o^2 + y_o^2 \qquad (5)$$

The second moment of mass is computed from

$$I_A = I_o + Wr^2/g \qquad (6)$$

where I_o = moment of inertia about center of mass = Wr^2/g

r = radius of gyration

Armored Personnel Carrier Analysis

The basic parameters used in the overturning analysis of an APC are

W = 24,000 lb (weight)

r = 37.54 in. (Radius of Gyration)

x_o = 50 in.

y_o = 39 in.

$w = 100$ in.

The critical instability angle, θ_c, which is the angle at which the center of gravity is directly above point A, is given by

$$\theta_c = \tan^{-1}(x_o/y_o)$$
$$= 52 \text{ deg.}$$

Even though the OVRTRN program has the capability to increase with rotation (θ) the BLOP code computed vertical location of the center of pressure, this option has not been used for this analysis. A total of 16 different blocks were used to define the aerodynamic model of the APC as shown in Figure 2. The majority of these blocks were used to model the ten (10) track wheels. The hull was modeled with five (5) blocks and one (1) additional block for the gun and hatch at the top of the vehicle.

The typical angular response of the vehicle is shown in Figure 3. These results are for a weapon yield of 10 KT. The critical overpressure for this yield for the case where there is no tie-down restraint is $p_o = 14.4$ psi. The response for slightly higher (14.5 psi) and lower (14.3 psi) overpressures is also shown in Figure 3. For the higher overpressure level, the critical angular rotation of $\theta_c = 52$ degrees is reached at $t = 1.44$ sec and the angular velocity is 13.9 degrees/sec. The solution was terminated at this time; however, the angular displacement and rotation would increase rapidly after this time since the gravity vector also contributes to the overturning moment.

The vulnerability curve for the APC is shown in Figure 4. Four curves are shown therein representing the overturning vulnerability for the case where there is no external tie-down restraint ($\gamma = 0$) and also three (3) magnitudes of restraint, i.e., $\gamma = 0.1$, 0.25 and 0.50. It is seen that for high weapon yields, the restraint is not as effective at increasing the overturning hardness as it is at lower weapon yields. If the tie-down system was oriented at 45 degrees with the ground surface and located at a point near the top of the hull (70 inches above the ground), the required total tie-down force of the restraint system would be

$$F = \frac{\sqrt{2}\,(39)}{100 + 70}\,\gamma W$$
$$= 7785\ \gamma$$

Thus for a restraint parameter of $\gamma = 0.5$, the tie-down system would have to supply a plastic resistance force of 3,893 lbs. This is not an unreasonable value that could be obtained from a rapidly deployed light gage cable and anchor system.

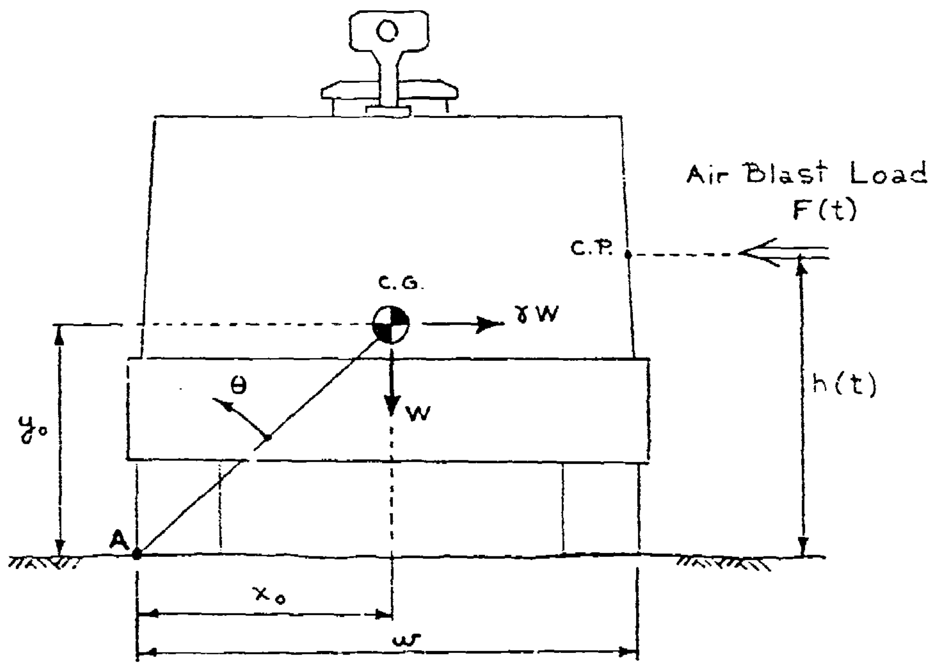
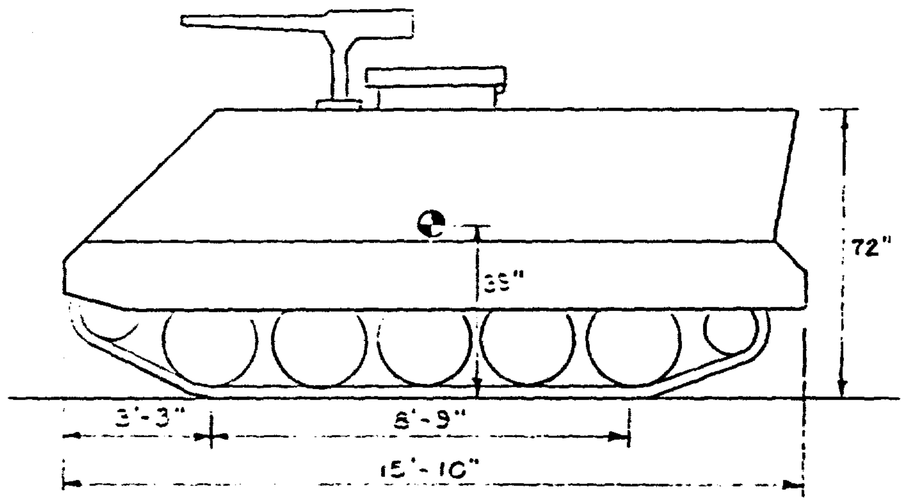
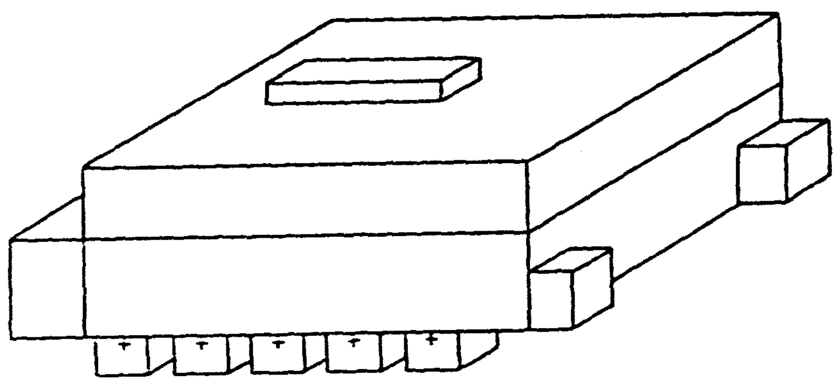


Figure 1. Rigid Body Overturning Model



Side View



Aerodynamic Model

Figure 2. Armored Personnel Carrier

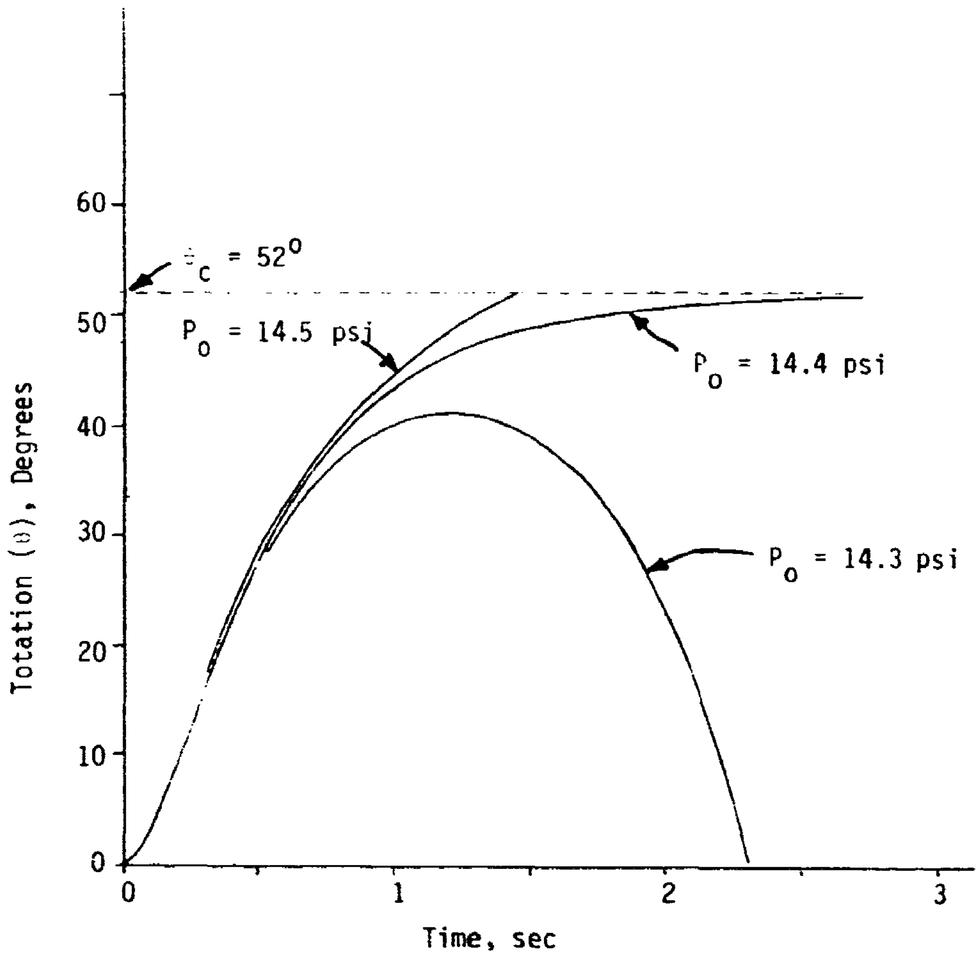


Figure 3. Rotational Variation for 10 KT Weapon Yield and Various Peak Overpressures (P_o)

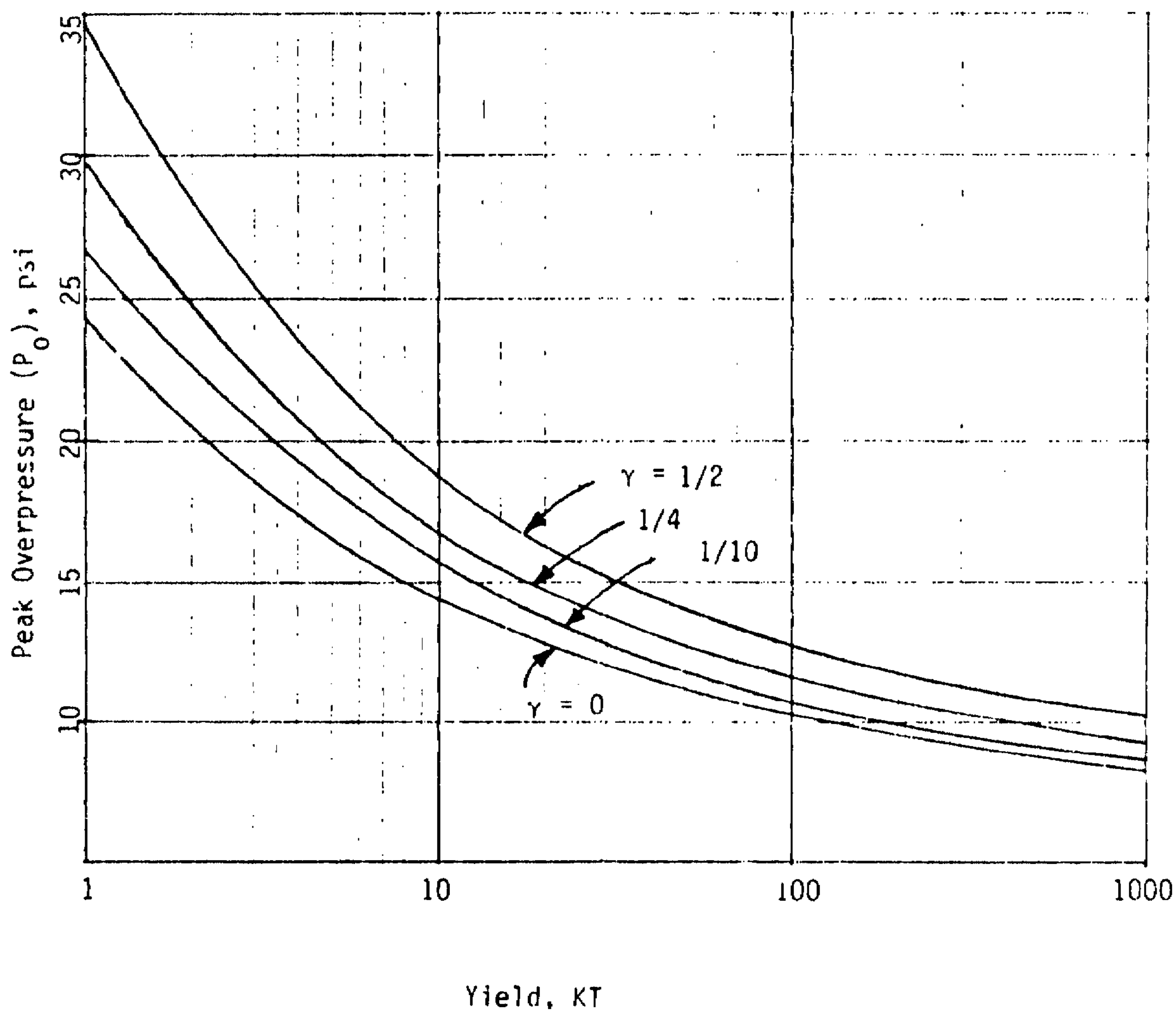


Figure 4. APC Overturning Vulnerability for Various Restraint Parameters (γ)